Form Approved REPORT DOCUMENTATION PAGE OMB No. 0704-0188 The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS. 3. DATES COVERED (From - To) 1. REPORT DATE (DD-MM-YYYY) 2. REPORT TYPE Final Technical Report 08/01/2017 - 12/31/2017 04/23/2018 4. TITLE AND SUBTITLE 5a. CONTRACT NUMBER Chalcogenide Semiconductor Research and Applications (CSRA) **5b. GRANT NUMBER** N00014-17-1-2903 5c. PROGRAM ELEMENT NUMBER 6. AUTHOR(S) 5d. PROJECT NUMBER Jaramillo, Rafael 5e. TASK NUMBER 5f. WORK UNIT NUMBER 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) 8. PERFORMING ORGANIZATION REPORT NUMBER SOCIEDAD MEXICANA DE MATERIALES, A.C. Av. Rio Mixcoac No. 36 Int. 802-B, Mexico 03230, Ciudad de Mexico, Mexico 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) 10. SPONSOR/MONITOR'S ACRONYM(S) ONR 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited. Scientific/Technological Research: Advances and Applications Information 13. SUPPLEMENTARY NOTES The Symposium mentioned in item 4 was carried out at the International Materials Research Congress (IMRC 2017), 20-25 August 2017 at the JW Marriott & Marriott Cancun Hotels in Cancun, Mexico. 14. ABSTRACT The symposium Chalcogenide Semiconductors Research and Applications (CSRA) and accompanying tutorial was held from August 20-22 as part of the International Materials Research Congress (IMRC) in Cancun, Mexico. The CSRA symposium was designed to bring together researchers in diverse fields that are connected by a shared focus on the processing-properties-performance connections in chalcogenide semiconductors and related electronic materials. The symposium features 15 invited speakers and 14 contributions, and attendees from Israel, the USA, Mexico, Japan, and Singapore. 15. SUBJECT TERMS chalcogenide; semiconductors; phase-change; 2D materials; photovoltaics; thin films

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1. Symposium organizers

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<u>Bio</u>: Prof. Jaramillo's research interests sits in the big, fun space between materials science, solid state physics, and renewable energy technologies. His current interests can be characterized as defect engineering of chalcogenide semiconductors. Prof. Jaramillo received a PhD in Physics from The University of Chicago (advisor: T. F. Rosenbaum), and a BS and MEng both in Applied and Engineering Physics from Cornell University

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<u>Bio</u>: Prof. Golan's research interests are in the fields of nanocrystalline materials, thin films, interfacial phenomena, and chemical deposition of semiconductor thin films. Prof. Golan received a PhD and MSc in from the Department of Materials and Interfaces, Weizmann Institute of Science, and a BSc in Chemistry from Tel Aviv University.

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<u>Bio</u>: Dr. Lany is a computational materials scientist with a background in electronic structure calculations for semiconducting materials. He joined NREL in 2003 as a postdoctoral researcher. As a staff scientist, he is currently leading computational research activities in support of the Energy Frontier Research Center and the Solar Energy Technology Program. Dr. Lany received a PhD in Physics from the Universitat des Saarlandes in Germany.

2. Synopsis

Symposium Abstract

Chalcogenides has its origin in chalkos, a Greek word for bronze, assigned to copper-bearing minerals: chalcocite, chalcopyrite, etc. Over time, chalcogenides have come to signify compounds of metals with group-VI elements. Many of these are naturally-occurring crystals that are born as semiconductors: chalcocite (Cu₂S), pyrite (Fe₂S), chalcopyrite (CuFeS₂), chalcostibite (CuSbS₂), herzenbergite (SnS), galena (PbS), etc. They also include materials that are under widespread investigation for devices: transition metal di-chalcogenides (*eg.* MoS₂) for electronics and photonics, Cu(In,Ga)(S,Se)₂ and Cu₂ZnSnS₄ for photovoltaics, (Hg,Cd,Zn)Te for detectors and photovoltaics, Bi₂Se₃ for topological computing, etc. Chalcogenide semiconductors may be key to advancing many of the technical goals of the Office of Naval Research including materials for nanoelectronics combining new functionalities, phase change

materials for microelectronics and RF applications, and materials for infrared imaging. Chalcogenide opto-electronic materials exhibit a wide range of phenomena including layered crystal structures with anisotropic transport, ordering phenomena such as ferroelectricity and density waves, widely tunable band gaps, and strong interactions with light including excitonic effects. Understanding, controlling, and harnessing these phenomena requires a thorough understanding of the science and device implications of chalcogenide electronic materials.

There have been conferences in the past devoted to chalcogenide electronic materials, but over the years the theme has splintered into many subthemes. Researchers in this theme share an awareness of the challenges involved in the material preparation and characterization, and a passion for their wide range of applications. Chalcogenide Semiconductor Research and Application (CSRA) symposia are intended to organize and serve the needs of this growing community.

Meeting Summary

The CSRA symposium and tutorial took place over three days in August 2017 at the XXVI International Materials Research Congress (IMRC 2017). The symposium was well-attended by the international research community, with 15 invited speakers and 14 contributions and with attendees representing Israel, the USA, Mexico, Japan, and Singapore. By design, the topics covered were broad, with presentations ranging from thin film solar cells to single crystal topological materials. The emphasis throughout on the processing-properties-performance connections in chalcogenide materials lead to surprising and interesting connections between research fields that usually do not interact. The full meeting program reproduced below.

3. Location and Meeting Program

Dates of Event: August 20-22, 2017

Event venue: JW Marriott Cancun Resort & Spa, Cancun, Mexico. Tel: (52) (998) 848-9600

Event program:

Sunday, August 20 – Tutorial

- Session 1: Theory (9:00am 10:15am), Dr. Stephan Lany
 - o Introduction to Density Functional Theory and Electronic Structure
- Session 2: Experiment (10:15am 11am), Dr. Rafael Jaramillo
 - o Thin film growth
 - Characterizing phase and composition
- Session 3: Theory (11:15am 12:30pm), Dr. Prashun Gorai
 - o High-throughput computation
 - Application to thermoelectrics
 - o Databases
- Session 4: Experiment (12:30pm 1:30pm), Dr. Rafael Jaramillo
 - o Optoelectronic property measurement
 - o Advanced characterization

Monday, August 21

 Session 1: Fundamentals of chalcogenide electronic materials – Theory and disorder (8:30am – 11am)

- Invite 1: Lany, Stephan "Disorder and defects in chalcogenide photovoltaic materials"
- Invite 2: Makov, Guy "PROPERTIES OF A NOVEL NANOMETRIC CUBIC PHASE IN MONOCHALCOGENIDE SEMICONDUCTORS"
- Contrib 1: P Karuna Nair, simF.1-abs016, OPTICAL AND ELECTRICAL PROPERTIES OF COMPONENT THIN FILMS OF ANTIMONY CHALCOGENIDE SOLAR CELLS
- Contrib 2: Rafael Jaramillo, simF.1-abs012, Mechanism of Persistent Photoconductivity in Chemical Bath Deposited CdS thin films
- Invite 3: Gorai, Prashun "Computationally Guided Discovery of Chalcogenide Thermoelectric"
- Invite 4: Agarwal, Ritesh "THE ROLE OF DISORDER ON ELECTRONIC, STRUCTURAL AND POLAR DOMAINS IN PHASE CHANGE CHANCOGENIDES"
- Session 2: Chemical strategies for electronic materials design (12:30pm 2pm)
 - Invite 5: Mitzi, David "SEARCH FOR HIGH-PERFORM. EARTH-ABUNDANT MULTINARY CHALC. ABSORBERS FOR SOLAR ENERGY CONVERSION"
 - Contrib 3: Yuval Golan, simF.1-abs001, Chemical Epitaxy of Chalcogenide Semiconductors
 - Invite 6: Simpson, Robert "PHASE CHANGE CHALCOGENIDES BY DESIGN"
- Session 3: Beyond semiconductors (4:00pm 6:30pm)
 - Invite 7 Moodera, Jagadeesh "CREATING A FERROMAGNETIC TOPOLOGICAL INSULATOR: INTERFACE EXCHANGE AND QUANTUM TRANSPORT"
 - Contrib 4: Nidia G. García Peña, simF.1-abs058, ROD-SHAPED BISMUTH SULFIDE-GRAPHENE OXIDE COMPOSITES AS POSSIBLE PHOTOCATALYST FOR CO2 REDUCTION
 - Contrib 5: Sadasivan Shaji, simF.1-abs026, Tin sulfide nanoparticles and thin films synthesized by pulsed laser ablation in liquid
 - Invite 8: Mao, Zhiqiang "NOVEL LOW DIMENSINAL TERNAY TRANSITIONAL METAL CHALCOGENIDES WITH SEMINCONDUCTINGAND TOPOLOGICAL SEMIMETALLIC PEROPERTIES"
 - Contrib 6: Amanda Carrillo, simF.1-abs010, CuS thin films as a proposal of active material in SC devices: A complete study of CBD parameters
 - Contrib 7: Aizuddin Supee, simF.1-abs005, CHARACTERIZATION OF FeSxOy THIN FILMS PREPARED BY THREE-STEP PULSE ELECTROCHEMICAL DEPOSITION
 - Invite 9: Clarke, Simon "SOFT CHEMICAL CONTROL OF IRON-BASED SUPERCONDUCTORS AND RELATED COMPOUNDS"
- Poster session (6:30pm 8:30pm)

Tuesday, August 22

- Session 4: Advances in thin films (9:00am 11:00am)
 - Invite 10: Redwing, Joan "MOCVD GROWTH OF MONOLAYER AND FEW LAYER TRANSITION METAL DICHALCOGENIDE FILMS"
 - Contrib 8: Vineetha Vinayakumar, simF.1-abs003, Effects of rapid thermal treatments on the photovoltaic properties of CuSbS2 thin films
 - Invite 11: Bent, Stacey "NOVEL MOLYBDENUM SULFIDE HYBRID FILMS"
 - Contrib 9: Bindu Krishnan, simF.1-abs028, AgSb(SxSe1-x)2 thin films for photovoltaics
 - Contrib 10: David Avellaneda, simF.1-abs039, Thin films of Cu-Sn-S system, obtained by chemical bath deposition and thermal evaporation methods
 - Contrib 11: P Karuna Nair, simF.1-abs015, Sb2SxSe3-x THIN FILMS OF VARYING COMPOSITIONS IN SOLAR CELLS PRODUCED BY THERMAL EVAPORATION
- Session 5: Advances in microelectronics (12:30pm 2:00pm)
 - o Invite 12: Park, Jiwoong "Paper and Circuits, only Atoms Thick"
 - Contrib 12: Christopher Muratore, simF.1-abs029, 2D CRYSTAL CALIGRAPHY: NOVEL TECHINQUES FOR PATTERNING 2D MATERIALS AND DEVICES ON FLEXIBLE SUBSTRATES
 - Invite 13: Hongtao Lin (JJ Hu postdoc) "Chalcogenide glass for integrated graphene photonics"
 - Contrib 13: Diogenes Placencia, simF.1-abs013, INVESTIGATION OF CONTACT INTERFACES IN PbS NANOCRYSTAL DEVICES FOR OPTOELECTRONIC APPLICATIONS
- Session 6: Materials design for optoelectronics (4:00pm -5:15pm)
 - Invite 14: Zakutayev, Andriy "EMERGING CHALCOGENIDE SEMICONDUCTORS FOR PHOTOVOLTAIC ABSORBER APPLICATIONS"
 - Invite 15: Ravichandran, Jay "Optical Properties of Perovskite Chalcogenides: Materials for Visible to Infrared Applications"
 - o Contrib 14: P Karuna Nair, simF.1-abs017, Chemically deposited lead-, tin-, and antimony chalcogenide thin films and applications